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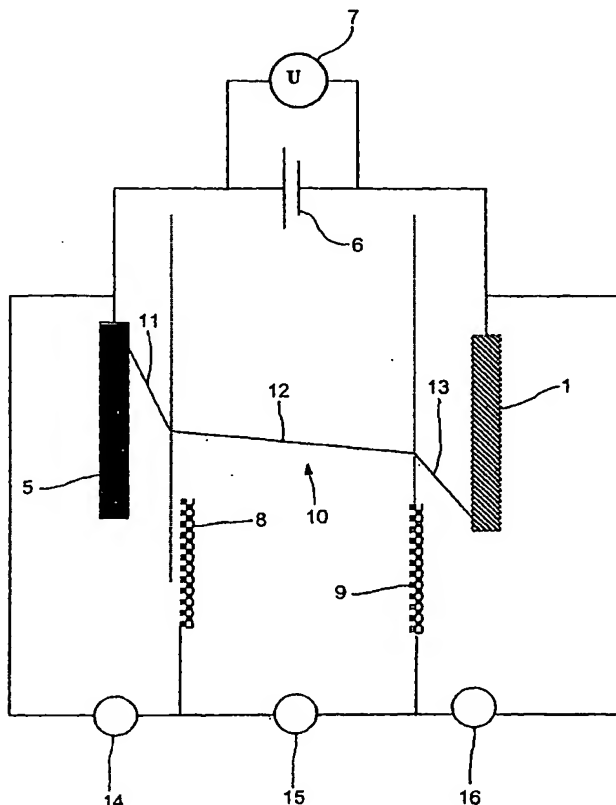
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(54) Title: DEVICE AND METHOD FOR MONITORING AN ELECTROLYTIC PROCESS



(57) Abstract: In manufacturing integrated circuits voids in the metal layer may readily form during electrolytic metal deposition. In order to avoid these faults which adversely affect the functionality of the circuits, the invention suggests to utilize for metal deposition an electrolysis device comprised of at least one anode and at least one cathode and in which at least one reference electrode is disposed at the surface of the at least one anode or at the surface of the at least one cathode. A voltmeter is respectively provided for detecting the electric voltages between the at least one anode and the at least one reference electrode and between the at least one reference electrode and the at least one cathode.



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## Device and Method for Monitoring an Electrolytic Process

### 5 Specification:

The invention relates to a device and a method for monitoring an electrolytic process, more specifically for electrolytically depositing metal onto a substrate.

- 10 Integrated circuits on wafers, more specifically made from silicon, are manufactured generally using etching and deposition processes in conjunction with photolithographic processes. Up to the present, metallic conductive patterns have been customarily produced using sputter processes for establishing electrical conductor connections on the wafers. For some years
- 15 galvanic processes have been increasingly utilized to manufacture integrated circuits on wafers. Aside from the electrolytic deposition of copper in what is termed the "back end" portion, i.e., for wiring the semiconductor structures produced on the wafer, the metal deposition of copper, nickel, gold and tin in what is termed the "packaging" process i.e., when metal is deposited onto chip
- 20 carriers, and in rewiring becomes increasingly important. All these requirements have in common that an electrolytic metal deposition process is initiated on a thin starting metal layer, the so-called seed layer, also termed plating base. For this purpose, the starting layer is placed in electric contact using suited mechanical contacts and is placed in an electroplating bath containing the
- 25 metal to be deposited in solution. Current is caused to flow through the starting layer and the counter electrode using an external current source, for example of a rectifier energized by the electric network, and a counter electrode so that metal is deposited onto the starting layer of the wafer. The amount and, as a result thereof, the coating thickness of the deposited metal is controlled through
- 30 Faraday's law.

Coating thickness distribution on the wafer may be positively affected using suited shields or segmented anodes (counter electrodes). Soluble anodes are

thereby used to keep the metal ion concentration in the electrolyte fluid constant or, alternatively, insoluble (inert) anodes, in which case the metal ion content must be kept constant, making additional provisions.

- 5 U.S. Patent No. 5,234,572 A describes a method for replenishing metal ions to a plating bath. To control the quantity of electricity transmitted between cathode and anode when current is applied, U.S. Patent No. 5,234,572 A suggests a measuring arrangement that measures the potential of the cathode (counter electrode) using a reference electrode additionally placed in the plating bath  
10 and made of the same metal as the anode. The quantity of electricity conducted is controlled such that the measured potential of the counter electrode may not be negative with respect to said reference electrode. This prevents metal ions from depositing on the counter electrode. In a preferred exemplary embodiment, the counter electrode and a soluble electrode (anode)  
15 are connected to a DC supply. A voltmeter is used for measuring the potential of the counter electrode relative to the reference electrode. The potentials at the counter electrode and at the soluble electrode, which vary with the current flow, are shown in a figure.
- 20 In case of electrolytic copper deposition, DE 199 15 146 C1 mentions that the copper deposition bath contains, in addition to the usual bath constituents, Fe(III) compounds for example and that these compounds cause the copper pieces to dissolve to form copper ions, yielding Fe(II) compounds in the process. The Fe(II) compounds formed are reoxidized to Fe(III) compounds at  
25 the insoluble anodes.

- All of the known electroplating baths contain, in addition to the metal ions to be deposited, auxiliary agents for influencing the metal deposition. As a rule, these agents are organic compounds for influencing the structure of the deposited  
30 layer on the one side and salts, acids or bases that are added for the purpose of stabilizing the bath and of increasing the electric conductivity thereof on the other side. The voltage required for deposition is reduced as a result thereof,

thus generating a minimum of Joule heat. This increases the safety of the process. Certain processes are only made possible by adding these agents.

Generally, conductive patterns are presently produced according to the damascene process. As recited in DE 199 15 146 C1, a dielectric layer is first applied on the semiconductor substrate for this purpose. The vias and trenches required for receiving the desired conductive pattern are etched in the dielectric layer, usually using a dry etch process. After a diffusion barrier (in most cases tantalum nitride, tantalum) and a conductive layer (in most cases sputtered copper) are applied, the depressions, i.e., the vias and trenches, are electrolytically filled using the "trench filling process". As copper is deposited on the entire surface, the excess must be subsequently removed from the unwanted locations, meaning from the zones outside the vias and trenches. This is achieved using what is termed the CMP process (Chemical Mechanical Polishing). Multilayer circuits can be made by reiterating the process i.e., by repeatedly applying the dielectric, made from silicon dioxide for example, forming the depressions by etching and depositing copper.

After the conductive pattern, more specifically made from copper, is made, it can be found out, in the polished sections intended for control, that metal defects (voids) readily form in the deposited structures, said defects possibly leading to a functional breakdown of the entire circuit.

Therefore the problem the present invention is facing is to avoid the drawbacks of the known devices and methods and more specifically to find measures permitting to reliably prevent such defects from forming.

In overcoming this problem the invention provides the device according to claim 1 and the method according to claim 7. Preferred embodiments of the invention are indicated in the subordinate claims.

The device according to the invention serves to monitor an electrolytic process,

more specifically the electrolytic metal deposition process, during manufacturing of integrated circuits of semiconductor substrates (wafers) and of circuit structures on chip carriers.

5 To explain the invention in closer detail, the term "wafer" will be used herein after to designate any workpiece. Likewise, the terms "deposition electrolyte" or "deposition electrolyte fluid" will be used to refer to the electrolyte fluid used for carrying out the electrolytic process. Alternatively, said fluid could also be an etch fluid if the electrolytic process is an electrolytic etch process. Possible  
10 electrolytic processes are both electrolytic deposition methods and electrolytic metal etching methods. In principle, the invention can also be utilized for other electrolytic processes than those mentioned herein. In the following description, the term "electrolytic deposition process" will be used to refer to all the other electrolytic processes as well.

15 In overcoming the problem, the invention provides a device and a method. The device is comprised of at least one anode and of at least one cathode that are in contact with an electrolyte fluid, an electric current flow being generated between them. At least one reference electrode is disposed at (near) the  
20 surface of the at least one anode or at (near) the surface of the at least one cathode. A voltmeter for determining the respective electric voltages between the at least one anode and the at least one reference electrode and between the at least one reference electrode and the at least one cathode is further provided in accordance with the invention. This arrangement permits to  
25 simultaneously register electrolytic partial processes at the various electrodes, this very provision permitting to also measure time-variant processes. It thereby makes no matter whether the electrodes are only immersed into the electrolyte fluid during measurement or whether a voltage is applied between cathode and anode only when the two electrodes are contacting the electrolyte fluid.

30 In a preferred application of the device in accordance with the invention, the cathode is a wafer or a chip carrier substrate and the anode a metal plate. In

this case, preferably metal is deposited onto the wafer or the chip carrier substrate during the electrolytic process.

The device in accordance with the invention is more specifically comprised of at least one first reference electrode which is disposed at (near) the surface of the at least one anode, and of at least one second reference electrode which is disposed at (near) the surface of the at least one cathode. Voltmeters for measuring the electric voltages between the at least one anode and the at least one first reference electrode, between the at least one first and the at least one second reference electrode and between the at least one second reference electrode and the at least one cathode are further provided. This monitoring device serves to measure the electric voltages between the anode and the first reference electrode, between the first reference electrode and the second reference electrode and between the second reference electrode and the cathode.

Comprehensive tests showed that the defects (e.g. voids) in the deposited metal layers are due to the fact that the metal deposition baths used are capable, under certain conditions, of removing metal from the starting layers:

When a wafer provided with a starting metal layer is immersed in the metal deposition solution, no external voltage is applied to the starting layer at first. Accordingly, an equilibrium potential is achieved at the phase boundary between the starting layer and the electrolyte solution as soon as the two are coming into contact. Under the usual conditions applied for depositing metal, more specifically copper, onto the starting layer, the potential of the starting layer relative to the metal dissolution is positive so that said starting layer slowly dissolves in the deposition solution.

Metal starting layers which are utilized on wafers are generally very thin for reasons related to cost and process. For example, in typical structures (trenches, vias of e.g., 0.1 - 0.2  $\mu\text{m}$  wide and about 1  $\mu\text{m}$  deep) made for the

damascene process, the starting layers usually are from about 5 - 25 nm thick. By contrast, the starting layers on the surfaces of the wafers are about 100 nm thick. Such type layers can be quickly removed, at least within the structures, during immersion in the electrolyte solution since the etch rate in the electrolyte solutions used is quite high. In a typical copper electrolyte containing about 180 g/l sulfuric acid and 40 g/l copper in the form of copper sulfate, the etch rate is about 10 nm/min under usual electrolysis conditions. Under these conditions, the coating thickness that remains prior to metal deposition may, under certain circumstances, not suffice to ensure reliable metal coating. The etch rate depends, inter alia, on the type of electrolyte solution used, the conditions chosen for the deposition process and the type of starting layer.

This problem cannot be overcome by shortening the time between immersion and the start of the deposition process since a certain minimum processing time must be observed after immersion in order for example to completely wet the wafer to be coated with fluid prior to starting metal deposition. Accordingly, the time window available for the process of electrolytically depositing metal onto the starting layer is but a narrow one. A particular problem is that, due to the plurality of possible influencing variables, the size of the time window for the process cannot be determined so that the result of metallization is left to chance only.

The thin starting metal layer is particularly sensitive to fluctuations of the deposition process and to corrosion. The slightest reduction in the thickness of this layer may suffice to jeopardize the safe start of the process in the nanostructures for example.

It is therefore very important to precisely control the immersion and wetting procedures. Technically, such a control is not readily possible because of the lack of electrical contact between the electrolyte fluid and the wafer prior to immersion and of the electrolyte dependent equilibrium potential obtained after immersion. Depending on the electrolyte composition, the starting layer may

corrode to a greater or lesser, unforeseeable extent.

- It has been found that the parameters that more specifically influence the metal removal are the partial voltages which, summed, yield the total electric voltage
- 5 (clamp voltage) applied between anode and cathode:

- During electrolytic metal deposition, a current flows between anode and cathode. An electric voltage composed of the sum of the partial voltages mentioned is needed to generate said current flow. The total voltage is more
- 10 specifically the result of the sum of anodic and cathodic charge transfer overvoltage, polarization overvoltages and crystallization overvoltages and also of concentration overvoltages and of the voltage drop due to the electrolyte resistance and the voltage drops in the electrical feed lines.
- 15 As a rule, it is not known how the measurable clamp voltage distributes between the individual voltages. More specifically, variations in the distribution cannot be registered as only the clamp voltage of the current source e.g., of the rectifier is known. If, during deposition, one of the resistances mentioned or one of the overvoltages listed varies or if they fluctuate between various wafers to
- 20 be processed, it will, at the best, not be possible to interpret the resulting measurable change of the clamp voltage. At the worst, this change will not even be noted so that metal will possibly be removed with no possibility to find out about it.
- 25 As in the semiconductor technology the process safety and the reproducibility of the methods are of prime importance, means had to be found to register the partial voltages. Variations during the process must be interpreted and identified in order to permit control and correction of the process.
- 30 In order to at least detect variations in the voltage drop that are due to the electric resistance of the electrolyte, reference electrodes are utilized, which are disposed directly on the surface of the anode or cathode. For this purpose, the

reference electrodes are to be brought so close to the surfaces that the potential can be measured directly at the respective one of the surfaces. The reference electrodes can for example be brought so close to the respective one of the surfaces that the spacing therefrom is less than 1 mm, for example  
5 0.2 mm. More specifically, the reference electrodes may also be arranged for example in the plane of the anode's or cathode's surface beside the surface, but in immediate proximity thereto, although not directly in front of said surface. The reference electrodes thereby need not be brought to contact the surfaces. Another possibility consists in placing a small container containing a conductive  
10 electrolyte on the respective surface or in proximity thereto, the reference electrode in said container permitting to detect the potential at the surface.

In a preferred embodiment of the invention, two reference electrodes are provided: the first of the two reference electrodes is arranged at the surface of  
15 the anode and the second reference electrode at the surface of the cathode. As the two reference electrodes are disposed in immediate proximity to the respective one of the electrodes, the influence of the voltage drop due to the electric resistance of the electrolyte can be detected separately in the form of the electric voltage between the two reference electrodes. The other voltage  
20 drops measured between a respective one of the reference electrodes and the anode or cathode at the surface of which said electrodes are disposed include the voltage drops occurring in proximity to the anode or cathode surface and more specifically the charge transfer, crystallization and concentration overvoltages.

25 The various voltage drops in different regions of the electrolytic cell can thus be detected and, as a result thereof, the influence of the afore mentioned factors (such as the type of the electrolyte solution, the properties of the starting layer and others) can be detected separately and analyzed accordingly. Variations  
30 due to the influencing variables mentioned may thus be identified so that appropriate provisions can be made in the event of such changes.

An advantage of the invention is that existing electroplating plants can be readily retrofitted with the means of the invention since no substantial structural extension is needed.

- 5 Any reference electrode can be utilized to measure the variations mentioned  
Stable reference electrodes more specifically contain a metal that is in  
equilibrium with a hardly soluble salt of said metal and an electrolyte. Such type  
reference electrodes are for example electrodes of the second or third order  
since these electrodes provide a constant reference potential. Reference  
10 electrodes of the second order are reference electrodes in which the  
concentration of the potential-determining ions is determined by the presence  
of a hardly soluble compound the ions of which are the same as the potential-  
determining ions. Reference electrodes of the third order, by contrast, are  
reference electrodes in which the activity of the potential-determining ions is  
15 determined by the presence of two solid phases. Reference electrodes of the  
second order are more specifically the calomel electrode, the silver/silver  
chloride electrode, the mercuric sulfate electrode and the mercuric oxide  
electrode. Reference electrodes of the third order may for example be a zinc  
rod that is in equilibrium with a solution of calcium ions in the presence of a  
20 precipitate made from zinc and calcium oxalate.

- One reference electrode is mounted in proximity to the anode, another in  
proximity to the wafer. The process is controlled by measuring the voltage  
between the anode and the first reference electrode, between the first  
25 reference electrode and the second reference electrode and between the  
second reference electrode and the cathode during the electrolytic process.

- The voltage measured between the first reference electrode and the second  
reference electrode is the result of variations of the electrolyte resistance which  
30 are indicative of the unstable composition of the electrolyte or of the irregular  
fluid flow within the processing tank.

Variations of the voltage measured between the first reference electrode and the anode are additionally indicative of an unstable anode process. With a soluble anode being used, this may be due to the consumption of the anode, to a change in the anode film or to a varying anode geometry. With an inert  
5 (insoluble) anode, such a change in the measured voltage may also be indicative of a failure of this anode (the active anode layer may for example peel off) or of poor redox species, e.g., Fe(II) and Fe(III) compounds, supply to the anode, for example in the event the method described in DE 100 15 146 C1 is performed.

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Variations of the voltage measured between the second reference electrode and the cathode are indicative of an unstable cathode process such as an altered thickness of the starting layer, for example because this layer is attacked by the metal deposition solution or because the layer has never been  
15 thick enough.

To control the process, more specifically to prevent the starting layer from corroding, a voltage difference between the starting layer and the nearest reference electrode, the second reference electrode for example, can be  
20 applied by a power rectifier prior to immersion. The proper choice of the potential of the starting layer permits to prevent it from corroding during immersion and possibly in the wetting phase as well. In order to obtain a useful result of the measurement, the respective one of the reference electrodes must be brought as close as possible to the associated electrode. However, the  
25 workpiece (the cathode for example) and the counter electrode (the anode for example) must thereby be prevented from being unshielded in order for the deposited metal to be distributed as uniformly as possible.

As stable reference electrodes more specifically contain a metal that is in  
30 equilibrium with a hardly soluble salt of said metal and an electrolyte, there is a risk that the electrolyte of the electrolytic process be contaminated by the electrolyte of the reference electrode. Such a contamination has to be

prevented by all means. In order to overcome this problem as well, the reference electrodes contact the surface of the anode or of the cathode through at least one capillary. In that the measurement of the voltages between the reference electrodes and between a respective one of the reference electrodes and the anode and cathode, respectively, is a high resistance measurement, but a very little current flows through the measuring arrangement. As a result, the capillary can be very thin so that contamination of the electrolyte of the electrolytic process through the electrolytes of the reference electrodes is minimized.

Another improvement with regard to this problem is achieved in that electrolyte fluid of the electrolytic process is supplied to the respective one of the reference electrodes via the capillaries. The electrolyte of the reference electrode is thus prevented from entering by diffusion into the deposition electrolyte.

To electrolytically deposit metal, more specifically copper, onto a semiconductor substrate, customary electroplating arrangements, made from platinum for example, can be utilized in which the anode and the semiconductor substrate are paralleled and oriented horizontally or tilted from horizontal. The anode and the semiconductor substrate can also be oriented vertically. The two electrodes are located in a tank configured to suit the purpose, a cylindrical tank for example, which accommodates the electrolyte fluid and the electrodes. Usually, the anode is disposed on the bottom of the cylindrical tank and the semiconductor substrate in the upper portion thereof. To generate a defined fluid flow, the electrolyte fluid can flow through the tank in a certain manner. The reference electrodes may be housed in separate containers communicating with the cylindrical tank via the capillaries mentioned. The capillaries are disposed in the wall of the tank in such a manner that they are located in immediate proximity to the respective one of the electrodes.

Another advantage of the present invention is that the device in accordance with the invention and the method permit to control the various partial

processes which have been described as taking place at the various electrodes, with the possibility of measuring certain voltages (potentials) concurrently. This provision permits to locate problems in current transfer.

- 5 The invention will be described in closer detail with reference to the following figures in which:

**Fig. 1** is a schematic cross section of a structure (trench, via) in a dielectric on a semiconductor substrate,

- 10 **Fig. 2** is a schematic representation of the potential differences in an anode and cathode arrangement with a respective reference electrode being provided in proximity to the anode and in proximity to the cathode,

**Fig. 3** is a schematic sectional view of a deposition cell,

- 15 **Fig. 4** is a schematic view of a deposition cell for problem analysis of current fluctuations during deposition.

**Fig. 1** shows the coating thickness distribution of the starting layer 2 in proximity to and within a structure 4 in a dielectric layer 3 on a semiconductor substrate. In the present case, the structure 4 is 0.2  $\mu\text{m}$  wide and about 1  $\mu\text{m}$  deep. At the surface of the substrate, the starting layer 2 is approximately 100 nm thick. The starting layer 2 is much thinner at the bottom of the structure 4, though. There, it is only 5 - 25 nm thick. In this lower region, there is the risk that the layer 2 is removed to such an extent during immersion and subsequent wetting of the starting layer 2 with a metal deposition electrolyte that no metal or but a very thin layer thereof is left at the bottom of the structure 4. As a result, no metal can be deposited onto this site during the subsequent electrolytic metal plating process.

- 30 **Fig. 2** is a schematic illustration of the potential difference between the anode 5 and the cathode 1 in the space containing the electrolyte. Current delivered by a current supply 6 flows between anode 5 and cathode 1. The current supply 6

may be a power rectifier for example. The voltage **U** delivered by the current supply **6** is measured using a voltmeter **7**. The voltage **U** is also termed clamp voltage.

- 5 In proximity to the anode **5** there is disposed a first reference electrode **8**. Likewise, a second reference electrode **9** is disposed in proximity to the cathode **1**.

10 The potential difference in the space containing the electrolyte between the anode **5** and the cathode **1** is labeled with the numeral **10**. For simplification sake, the potential difference **10** is divided in only three portions **11**, **12** and **13**, the portions **11** and **13** being generated by the diffusion and crystallization overvoltages and portion **12** arising from the voltage drop generated by the electric resistance of the electrolyte.

15 The voltage drops mentioned can be determined in a simple manner by measuring the electric voltages between the anode **5** and the first reference electrode **8** using the first voltmeter **14**, between the first reference electrode **8** and the second reference electrode **9** using the second voltmeter **15** and  
20 between the second reference electrode **9** and the cathode **1** using the third voltmeter **16**. The sum of the partial voltages **11**, **12**, **13** as measured by the voltmeters **14**, **15** and **16** yields the clamp voltage **U**.

25 The voltage drop **11** is measured by voltmeter **14**, the voltage drop **12** by voltmeter **15** and the voltage drop **13** by voltmeter **16**.

**Fig. 3** is a schematic illustration of an arrangement for electrolytically depositing metal on a semiconductor substrate **1**. The arrangement has a tank **20** and an anode **5** on the bottom of the tank **20** and a semiconductor substrate **1**  
30 employed as a cathode in the upper portion of the tank **20**. The tank **20** is filled with electrolyte fluid **22** to level **21**. Fluid **22** can for example enter the tank **20** from the bottom and flow through the anode **5**. The anode **5** is preferably

perforated for this purpose.

In the wall of tank 20, a first capillary 23 is embedded in proximity to the anode 5 and a second capillary 24 in proximity to the semiconductor substrate 1.

5 Electrolyte fluid can flow in a small volume flow through said capillaries 23, 24 into the reference electrode containers 25 and 26 mounted to the sides thereof. This prevents electrolyte fluid, which may be contained in said containers 25, 26 and has another formulation than the deposition fluid 22, from entering tank 20. The containers 25, 26 accommodate a first reference electrode 8 and a  
10 second reference electrode 9 that are connected through electrical lines to voltmeters (not shown).

Fig. 4 is a schematic illustration of a deposition cell. The anodes 5 are formed by an inert anode basket which is surrounded by a diaphragm (not shown  
15 herein) and holds the metal to be deposited, e.g., in the form of shot or pellets. The anodes 5 are located outside tank 20. They are coupled through conduits 29 that are coupled into tank 20 by way of shields 28. The shields 28 act as virtual anodes. A first reference electrode 8 is disposed in proximity to the anodes 5. A second reference electrode 9 is likewise disposed in proximity to  
20 the cathode 1. The electric voltages between the cathode 1 and the second reference electrode 9, between the second reference electrode 9 and the first reference electrode 8 and between the first reference electrode 8 and the anodes 5 are measured using the voltmeters 16, 15, 14, respectively. The tank 20 is completely filled with electrolyte fluid 22.

25

A test performed in practical operation showed that the amount of metal deposited onto the cathode 1 was not sufficient. Concurrently, although the voltage applied was 20 V, a very low current of about 100 mA only was measured between the cathode 1 and the anodes 5 as compared to usual  
30 deposition cells (10 A at only 2 - 3 V). The reasons therefore could have been for example:

1. insufficient electric contact between the cathode 1 and the electrolyte fluid 22,
2. disruption of the conduits 29,
3. insufficient electric contact between the anodes 5 and the electrolyte fluid 22 or
4. deficient electrolyte flow through the conduits 29.

In designing the measuring device in accordance with the invention, which is comprised here of the two reference electrodes 8, 9 and the voltmeters 14, 15, 16, the following results could be obtained simultaneously in accordance with the invention so that fault finding was made possible:

- Between the cathode 1 and the second reference electrode 9 a voltage of about 0.5 V that was stable over time was measured using the voltmeter 16.
- The voltage between the two reference electrodes 8, 9 as measured by voltmeter 15 was 1 V and stable over time. By contrast, the voltage between the first reference electrode 8 and the anode 5 was approximately 18.5 V and varied in time with the overall voltage.
- These results permitted to dismiss the afore mentioned reasons 1, 2 and 4. The problem could be eliminated by improving the electrical contact established at the transition between the anodes 5 and the electrolyte fluid 22. It was found out that the diaphragm disposed around the anode basket was no longer wetted in the electrolyte fluid.
- In a further example an electrolytic copper bath 22 was used to deposit a copper layer on a semiconductor wafer 1. The wafer 1 was provided with a copper seed layer which was approximately 100 nm thick. The copper seed layer was coated with a photoresist layer having vias and trenches exposing the copper seed layer. The copper bath 22 contained copper sulfate, sulfuric acid and a minor amount of sodium chloride as well as generic additive components that are usually used to optimize physico-mechanical properties. The bath 22

was operated in a deposition tank 20 with a design of the tank as shown in Fig. 4. The anode 5 was insoluble, being made from an expanded metal sheet of titanium, which was activated with noble metal (e.g. platinum). In order to maintain a nominal copper ion concentration in the bath 22 copper pieces were dissolved in a separate container (not shown herein) which was in fluid connection with the tank 20. In order to promote copper dissolution the bath 22 also contained Fe(II) and Fe(III) compounds. A bath suitable for this purpose is described in DE 199 15 146 C1 for example.

After the wafer 1 had been brought into contact with the copper bath 22 and after a certain idle time thereafter, current was switched on to have the wafer 1 be metallized. Prior to switching the current on the copper seed layer risked to be etched by the copper plating bath 22 or, more specifically, by the Fe(III) ion compounds in this bath 22. For this reason electroplating was a problem if the copper seed layer at least partially dissolved prior to first copper deposition.

Electroplating was effected by an electrolytic current flowing between the wafer 1 and the anode 5. Safe initiation of copper deposition could easily be determined by measuring the voltage between the wafer 1 and the reference electrode 9 over time in order to ascertain whether safe wetting of the wafer 1 occurred and whether a sufficiently thick copper seed layer was still present at the surface of the wafer 1. If the voltage was not determined to be in the value range expected, deficient electroplating was expected.

Furthermore the voltage between the wafer 1 and the reference electrode 9 was measured. Practicing this measurement during the entire electroplating process a defined potential control of the wafer 1 was achieved. This also guaranteed process safety during the entire copper plating process including the method steps of immersion and wetting of the wafer 1. It turned out that seed layer etching could be prevented if a suitable voltage was applied to the wafer 1. Under these conditions the wetting period of the wafer 1 could be optimized, i.e. extended.

At the same time processing was also found to be influenced by imponderable conditions at the anode 5. It turned out that too high a plating rate would lead to a material transport in the plating bath 22 being rate determining (reaction of Fe(II) to Fe(III)). This could lead to water electrolysis and hence generation of oxygen gas bubbles at the anode 5. At the same time the anode potential was measured to shift. Under unfavourable conditions this shift was detected by measuring the voltage between the anode 5 and the reference electrode 8. Therefore by ascertaining a voltage which was outside the normal range the processing parameters could be suitably adjusted in order to prevent deficient processing.

Hence, it turned out that processing deficiencies, which were caused by deficient anodic and/or cathodic processes, could be detected, if the voltages mentioned and the clamp voltage deviated from the normal ranges. Only by simultaneously measuring these voltages as well as the clamp voltage between the wafer 1 and the anode 5, the causes for the deficiencies could be found out.

It is understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications and changes in light thereof as well as combinations of features described in this application will be suggested to persons skilled in the art and are to be included within the spirit and purview of the described invention and within the scope of the appended claims. All publications, patents and patent applications cited herein are hereby incorporated by reference.

**Listing of numerals:**

	<b>1</b>	semiconductor substrate (cathode)
	<b>2</b>	starting layer (seed layer, plating base)
<b>5</b>	<b>3</b>	dielectric layer
	<b>4</b>	structure in the dielectric layer <b>3</b>
	<b>5</b>	anode
	<b>6</b>	current supply (voltage source)
	<b>7</b>	voltmeter for the clamp voltage <b>U</b>
<b>10</b>	<b>8</b>	first reference electrode
	<b>9</b>	second reference electrode
	<b>10</b>	potential difference
	<b>11</b>	voltage drop at the anode <b>5</b>
	<b>12</b>	voltage drop in the electrolyte <b>22</b>
<b>15</b>	<b>13</b>	voltage drop at the cathode <b>1</b>
	<b>14, 15, 16</b>	voltmeters
	<b>20</b>	tank
	<b>21</b>	fluid level
	<b>22</b>	electrolyte fluid
<b>20</b>	<b>23, 24</b>	capillaries
	<b>25, 26</b>	reference electrode containers
	<b>27</b>	electrical lines
	<b>28</b>	shields (virtual anode)
	<b>29</b>	conduit
<b>25</b>	<b>U</b>	clamp voltage

## Patent Claims:

- 5 1. A device for monitoring an electrolytic process, comprising at least one anode and at least one cathode, at least one reference electrode being disposed at the surface of the at least one anode or at the surface of the at least one cathode, at least one voltmeter being respectively provided for detecting the electric voltages between the at least one anode and  
10 the at least one reference electrode and between the at least one reference electrode and the at least one cathode.
- 15 2. The device according to claim 1, **wherein** at least one first reference electrode is disposed at the surface of the at least one anode and at least one second reference electrode is disposed at the surface of the at least one cathode and wherein a voltmeter is respectively provided for detecting the electric voltages between the at least one anode and the at least one first reference electrode, between the at least one first and the at least one second reference electrode and between the at least one  
20 second reference electrode and the at least one cathode.
- 25 3. The device according to one of the afore mentioned claims, **wherein** the at least one reference electrode communicates through capillaries with the surface of the at least one anode or with the surface of the at least one cathode.
- 30 4. The device according to claim 3, **wherein** means are provided by means of which electrolyte fluid is deliverable through the capillaries to the at least one reference electrode.
5. The device according to one of the afore mentioned claims, **wherein** the at least one anode and the at least one cathode are paralleled and

oriented horizontally or tilted from horizontal.

6. The device according to one of the afore mentioned claims, **wherein** the cathode is a wafer or a chip carrier substrate and the anode is a metal plate.

7. A method of monitoring an electrolytic process in an electrolytic cell comprised of at least one anode and of at least one cathode, at least one reference electrode being disposed at the surface of the at least one anode or at the surface of the at least one cathode, at least one voltmeter being respectively provided for detecting the electric voltages between the at least one anode and the at least one reference electrode and between the at least one reference electrode and the at least one cathode,

said method involving the following method steps:

- a) providing an electric current flow between the at least one anode and the at least one cathode,
- b) concurrently detecting the respective electric voltages between the at least one anode and the at least one reference electrode and between the at least one reference electrode and the at least one cathode.

8. The method of claim 7, **wherein** at least one first reference electrode, which is disposed at the surface of the at least one anode and at least one second reference electrode, which is disposed at the surface of the at least one cathode are provided,

method step b) including the following partial method steps:

- b1) detecting the electric voltage between the at least one anode and the at least one first reference electrode,
- b2) detecting the electric voltage between the at least one first reference electrode and the at least one second reference electrode and

b3) detecting the electric voltage between the at least one second reference electrode and the at least one cathode.

5 9. The method according to one of the claims 7 and 8, **wherein** the at least one reference electrode is brought into contact with the surface of the at least one anode or with the surface of the at least one cathode by way of capillaries.

10 10. The method according to claim 9, **wherein** electrolyte fluid is delivered through the capillaries to the at least one reference electrode.

15 11. The method according to one of the claims 7 - 10, **wherein** the at least one anode and the at least one cathode are paralleled and oriented horizontally or tilted from horizontal.

12. The method according to one of the claims 7 - 11, **wherein** the cathode is a wafer or a chip carrier substrate and wherein the anode is a metal plate and wherein the metal is electrolytically deposited on the wafer.

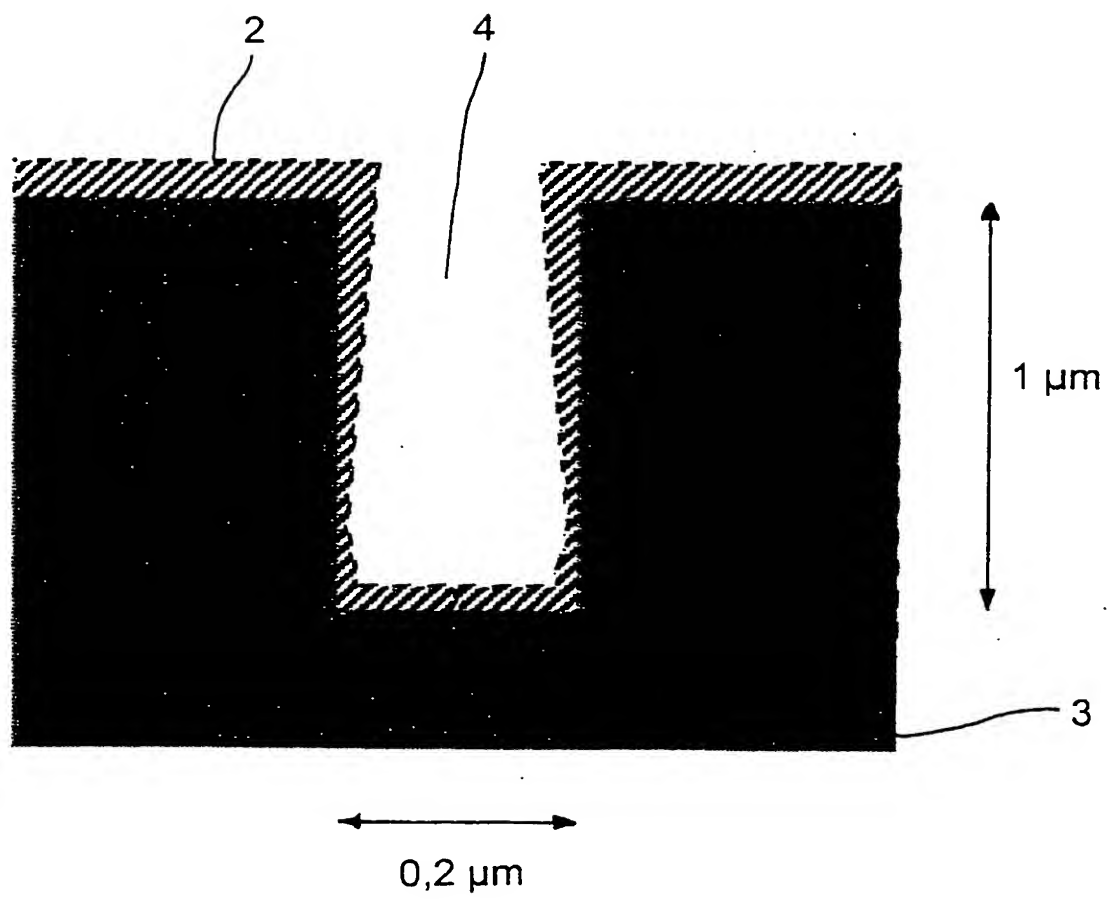


Fig. 1

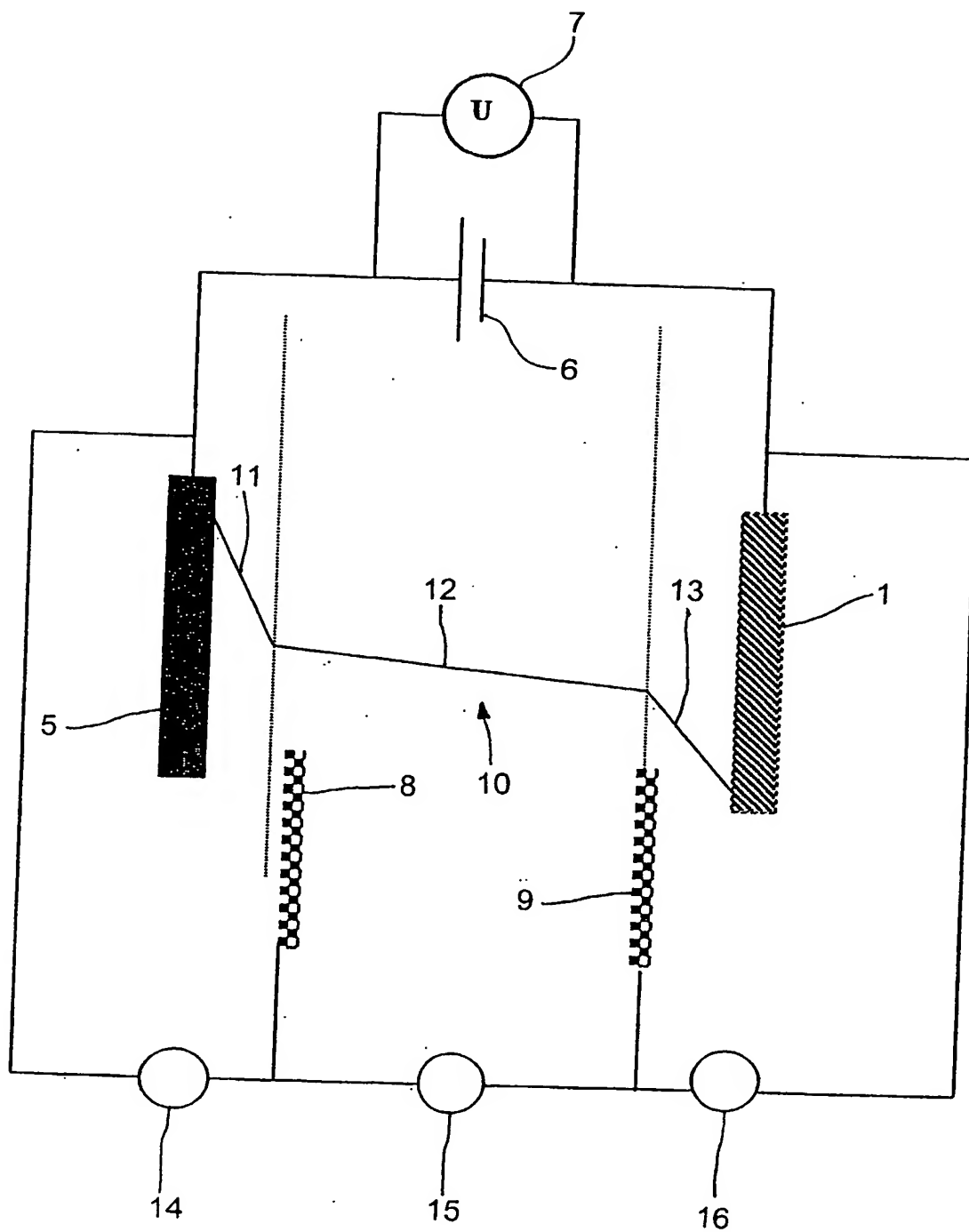


Fig. 2

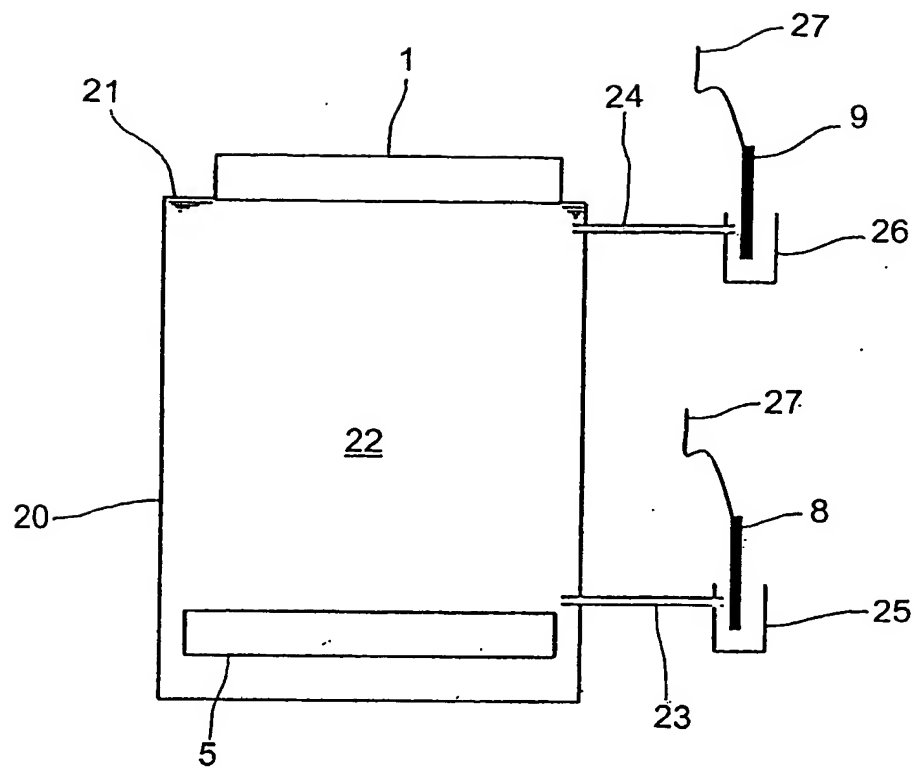
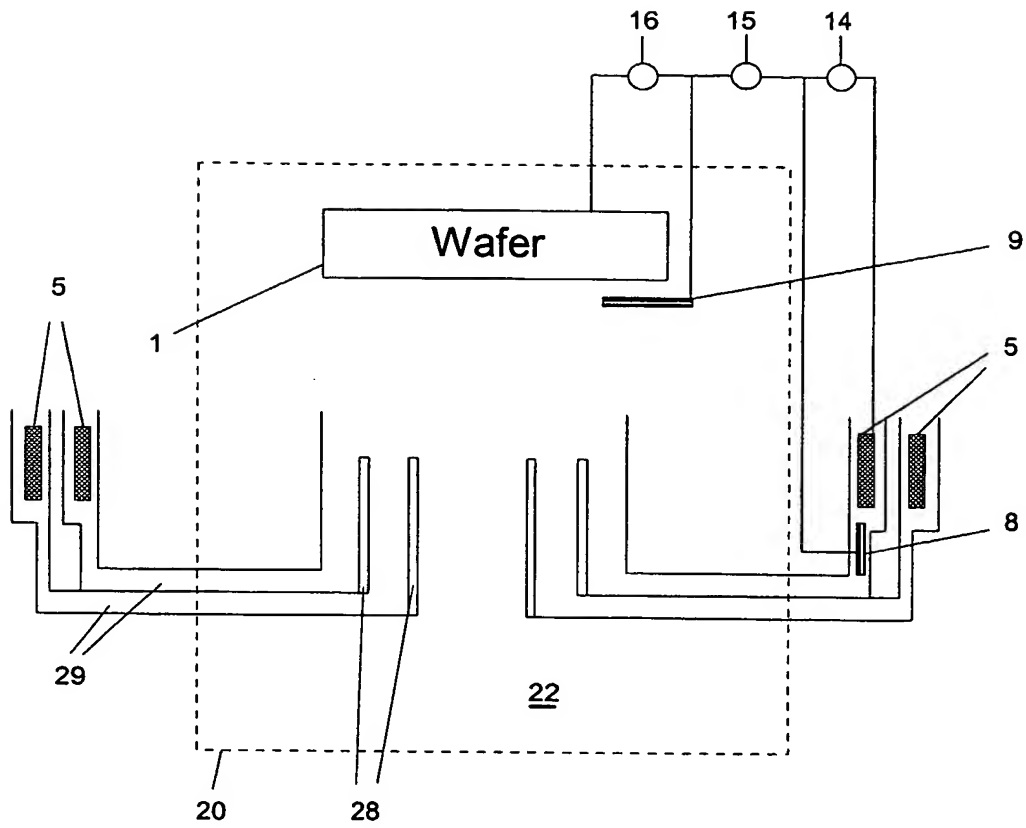


Fig. 3

**Fig. 4**

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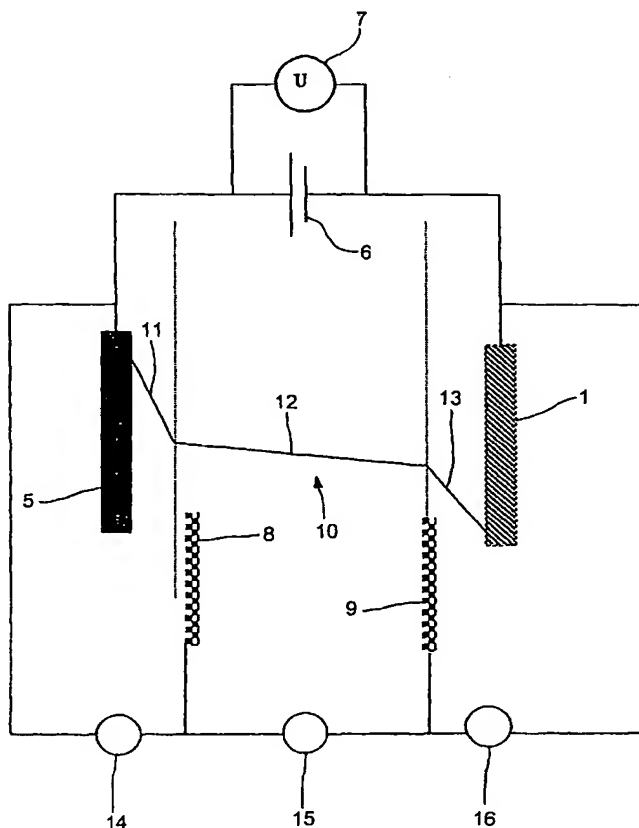
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[Continued on next page]

(54) Title: DEVICE AND METHOD FOR MONITORING AN ELECTROLYTIC PROCESS



(57) Abstract: In manufacturing integrated circuits voids in the metal layer may readily form during electrolytic metal deposition. In order to avoid these faults which adversely affect the functionality of the circuits, the invention suggests to utilize for metal deposition an electrolysis device comprised of at least one anode and at least one cathode and in which at least one reference electrode is disposed at the surface of the at least one anode or at the surface of the at least one cathode. A voltmeter is respectively provided for detecting the electric voltages between the at least one anode and the at least one reference electrode and between the at least one reference electrode and the at least one cathode.

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SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 C25D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the International search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 261 433 B1 (LANDAU UZIEL) 17 July 2001 (2001-07-17) column 14, lines 7-9	1
X	GB 871 203 A (ARTUR RIEDEL; FRANZ BACHMANN) 21 June 1961 (1961-06-21) claims 1-7	1, 3, 4, 7, 9, 10
X, P	PATENT ABSTRACTS OF JAPAN vol. 2003, no. 03, 5 May 2003 (2003-05-05) & JP 2002 322592 A (HITACHI LTD), 8 November 2002 (2002-11-08) abstract	1, 5-7, 11, 12

☐ Further documents are listed in the continuation of box C.

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